**THE NATIONAL**
**SHIPBUILDING**
**RESEARCH PROGRAM**

Final Report on the Project

# TRACKING SYSTEM FOR AUTOMATIC WELDING

PHASE II - Improvement of Contact-Tip Life for Through-The-Arc Welding System

Cooperative Effort by;
Maritime Administration”of the U.S. Department of Transportation,
Newport News Shipbuilding and Drydock Company, CRC-EVANS
Automatic Welding, and Ingalls Shipbuilding, Inc.

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ABSTRACT

In Phase I of this project, an automatic seam tracking/adaptive control welding system, the M1OOO, was evaluated and weld-tested using the high heat, pulsed gas metal arc welding process. Phase I concluded with the finding that thru-the-arc seam tracking with computer control and adjustment of welding parameters was a viable technology. Potential savings in welding time would be possible if further development of hardware and computer software were achieved to more fully realize the potential of the system.

Needed improvement in consistency of system response to changing conditions in the weld were recognized. It was determined that the most efficient utilization of available funds was support of development of weld head contact tips, which could function over longer periods of continuous welding without need for replacement due to wear. That objective became the primary focus of Phase II, the results of which are the subject of this report.

The work reported involved the testing of the best identifiable candidate materials for improving contact-tip life. The material that provided the best results was the Series G, RWMA, Class 3 electrode material. It resulted in continuous running time of 99.8 minutes, significantly better than the 70 minutes minimum that was targeted. Another finding was that contact-tip life can be improved up to 77% by using an adaptive welding power supply which automatically compensates for varying contact-tip conditions.

The objective of this task was accomplished -the extension of continuous automated weld time to weld over 90 minutes by contact-tip improvement for MIG welding with high heat input. However, as recommended in the findings of Phase I, further development work in thru-the-arc weld tracking and parameter control should be addressed to needed improvement in the welding algorithms and further computer processing of arc data tasks, which were beyond the scope of this project.



O. J. Davis
SP 7 Program Manager

# PREFACE

This report presents the results of a project initiated by SP-7 Welding R&D Panel of the Ship Production Committee for the National Shipbuilding Research Program. The project was funded by the Maritime Administration of the U.S. Department of Transportation under Cost Sharing Contract MA-8O-SAC-O1O41.

The overall objective of the project was to evaluate an automatic seam tracking/adaptive control welding system, the M1OOO, for high heat input welding of thick sections (over 3/4” thick) of steel plate.

Program management was provided by Ben Howser and Mark Tanner of Newport News Shipbuilding and Drydock Co. Many support services were provided on a cost-sharing basis by the Welding Engineering Organization and by James Cameron, Manager of R&D, Electric Boat Division of General Dynamics. Development work was performed by the staff of Crutcher Resources, Evans Automatic Welding Company, Houston, Texas. Reprographics and distribution were provided by Ingalls Shipbuilding under the SP-7 chairmanship of L. G. Kvidahl and program management of O. J. Davis.

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FINAL REPORT

on

IMPROVEMENT OF CONTACT TIP LIFE
WITH M-1000 WELDING SYSTEM
(Purchase Order R2216-016)

to

ELECTRIC BOAT DIVISION
GENERAL DYNAMICS

from

CRC-EVANS AUTOMATIC WELDING

November 26, 1986

## INTRODUCTION

This work was undertaken to investigate various contact tip materials to prolong the useful life of the contact tip when used with the CRC-Evans Automatic Welding M-1000 system. The CRC-Evans M-1000 welder is a closed-loop, adaptive-feedback-controlled system. The system, under microprocessor control, automatically tracks the weld joint and varies the welding parameters in real time to provide a constant level of weld fill within a predetermined heat input range. One of the important algorithms in the software control system is contact tube-to-work distance (electrical stick-out). This is defined as the distance between the point within the contact tip where the electrical current is introduced and the surface of the molten weld pool. If this last point of electrical contact within the tip shifts, it causes an instantaneous change in the welding parameters (amperage, voltage). Thus, when the contact tip is worn sufficiently, this electrical contact point shifts erratically producing erractic system control.

The M-1OOO welding system was used experimentally in the production welding of 10-feet-long ring sections of 2-inch-thick HY-80 steel at the Quonset Point yard of Electric Boat. These welds were deposited in the 3G, vertical up welding position using 0.045-inch-diameter E1OO-S-1, Linde 95 filler wire with 95 A - 5 C02 shielding gas. The welds at Quonset Point were deposited at a heat input of 100 kilojoules with a travel speed of approximately 2 ipm.

The continuous welding time for one traverse of the vertical butt weld was about 60 minutes. However, the contact tips failed after 45-50 minutes of continuous welding which necessitated stopping to change contact tips before a complete traverse. Accordingly, Electric Boat set a minimum target life of a contact tip at 70 minutes of continuous welding under production conditions, i.e., heat input of 100 kj.

This Final Report summarizes the work done at CRC-Evans Automatic Welding from August 25 to November 26, 1986 to investigate alternative contact tip materials. It summarizes the materials, equipment, experimental procedures, and results of this work.

## MATERIALS

The base plate, filler wire, and contact tips are discussed in the following sections.

## Base Plate

A l-inch thick, 7-feet wide, and 20-feet long plate of plain carbon steel was obtained. The plate was flame cut lengthwise into nine (9) pieces. The plates were beveled by flame cutting to produce eight weld joints (four per side) with 45-degree included angle and a root spacing of l/2-inch. Backing bars, l/2-by 2-inches were welded to the plate. The test plate was erected vertically to provide eight butt joints, 20 feet long.

## Filler Wire

The filler wire that was purchased is 0.045-inch-diameter, E1OO-S-1, Linde 95. This is the filler wire used at Quonset Point.

## Experimental Contact Tips

There are two types of contact tips used with the M-1OOO welding system: (1) spade tip, as shown in Figure 1, and (2) blunt tip as shown in Figure 2. The spade tip is used for the initial passes where the joint is narrow. Most of the contact tips were the thinner-section, spade type.

The base line contact tip material, as used at Electric Boat, was a chromium-copper, powder metallurgy product. The contact tip materials evaluated were as follows:

| Series Designation | Type | Source |
|---|---|---|
| M | Base Line 0.2 Cr-O.02 Zr-4.5 Fe-Cu | Eberhard Yeager, Randolph, New Jersey |
| E | Ampcoloy 97 (RWMA-RWAA, Class 2, 0.5 Cr-O.l Fe-Cu) | Ampco Metals, Milwaukee, Wisconsin |

| | | |
|---|---|---|
| G | Ampcoloy 940 (RWMA-RWAA, Class 3, 0.4 Cr-O.l Fe-0.5 Si-Cu) | Ampco Metals |
| I | Copper with Tubular Tungsten Insert, Spade | Amax, Ann Arbor, Michigan |
| J | Copper with Molybdenum Wire Inserts, Blunt | Amax |
| K | Copper with Tubular Tungsten Insert, Blunt | Amax |
| N | One Percent Tungsten-Copper | Eberhard Yeager |
| P | Six Percent Tungsten-Copper | Eberhard Yeager |

## EQUIPMENT

The equipment used for this investigation is described in the following sections.

### M-1OOO Welding System

All of the contact tips were evaluated using a CRC-Evans M-1OOO welding system. The M-1OOO is a real-time, adaptive-controlled welding system that uses through-the-arc sensing technology to track the weld joint, maintain constant heat input, and control the welding parameters.

The small, portable, welding system is supported by and travels on a standard, Gullco track containing a rack for the rack-and-pinion drive. The system is controlled by an eight-bit, RCA 1802 microprocessor contained in a remote, computer-control cabinet. Welding parameters are entered using a 16-key, capacitive-touch, keyboard with a 16-character, alpha-numeric liquid-crystal-display (LCD) on the control cabinet. The system can be operated in a manual or fully-automatic adaptive-control mode. The M-1OOO welding carriage is shown in Figure 3.

## Welding Power Supply

The first five contact tips were evaluated using a 350-ampere, 100 percent duty cycle, CRC-Evans Synchro-Pulse CDT power supply. This is a synergic, constant-current pulsed-arc rectifier with a SCR secondary switching regulator. The use of this power supply was terminated for this evaluation because the self-regulation control system of the CDT was compensating for the change in contact-tip-to-work distance by changing the pulsing frequency. This resulted in prolonging the useful life of the contact tip by 77 percent, thus nullifying the experimental results.

The balance of the contact tip evaluations were made with a 350-ampere, 100 percent duty cycle, fixed frequency, SCR-controlled, pulsed arc Airco PA3A power supply. This power supply was used at Electric Boat for some of the production welding with the M-1OOO.

## EXPERIMENTAL PROCEDURES

The inside diameters of the candidate contact tips were measured using centerless-ground, precision plug gages. Five gages from 0.054- through 0.058-inch-diameter at O.001-inch increments were used. The diameter of the largest gage that could be inserted in the contact tip was recorded.

The contact tips were evaluated using the CRC-Evans M-1OOO system welding vertical up using the following welding parameters:

Travel Speed - 2.2-2.5 ipm
Average Voltage - 21.5 volts

Average Amperage - 175-185 amperes
Calculated Heat Input Range - 90-108 kilojoules/inch

The cumulative arc time for each contact tip was recorded by the M-1OOO.

The welding was continuous until the contact tip shorted into the weld pool. In most cases, this shorting occurred as the M-1OOO welding head moved toward the weld pool to compensate for an extension of the CTOD because of contact tip wear. In a few instances, the contact tip accidentally shorted to the side wall terminating that test. In these instances, the data were not included in the average.

After each series was completed, the failed contact tips were photographed. Then, the tip was cut off about l/8-inch from the end. The I.D. of the tips was measured optically. Most of the holes were elongated so the minor and major axes of the holes were recorded.

The maximum temperature at the tip of the contact tip during welding was determined by spot-welding a K-type, chromel-alumel thermocouple on the tip.

## RESULTS

The data for each of the contact tips are shown in Table 1. The base line Series M contact tips were the same as used at Quonset Point in production welding. The Series D contact tips were received and identified as a different composition from the Series M base line tips. However, subsequent chemical composition analyses showed that the Series D and Series M were the same composition. These electrodes are listed as Series M but identified as Ml-11 and D1-4, and D1O-11.

The base line Series M were evaluated using two different welding power supplies: (1) the synchronous, synergic CRC-Evans CDT for tips Ml-5, and (2) the fixed-frequency PA3A for the balance of the contact tips. As stated earlier, the CDT was abandoned because the CTOD-correcting software of the CDT compensated for CTOD changes, thus invalidating the analysis. The average arc time when using the CDT power supply was 124.0 minutes, compared to the 55.7 minutes when using the fixed-frequency Airco PA3A. This tip life of 55.7 minutes agrees very closely with the reported 45-50 minutes by Electric Boat.

The arc time to failure varied considerably within all of the series. Failures that occurred because of accidental shorting to the sidewall, or that occurred for reasons other than the M-1OOO welding head forcing the contact tip into the weld pool were eliminated from the averages, as shown by the footnote (a) in Table 1.

All of the contact tips are shown in Figures 4-13. The tips are shown in the as-welded condition and after the tip was trimmed about l/8-inch from the end. Most of the tips that ran for more than 30 minutes showed excessive erosion to one side of the hole. This suggests that wire cast was the principal cause of contact tip wear. The longest running Series G tips (average 99.8 minutes) showed less hole erosion than the other tips.

To attempt to explain the differences in tip life of the various series, Rockwell B hardness measurements were made on the contact tips that had the shortest and longest lives within the series. The tips containing inserts were not tested for hardness. These hardness measurements were made after the tip was run. Measurements were made at the tip and at the other end where the water-cooled collet kept the temperature low. The results were as follows:

| Tip No. | Tip Life, Minutes | Hardness, Rockwell B Tip | Hardness, Rockwell B Cold End |
|---|---|---|---|
| Base Line M-3 (CDT) | 53.9 | 77.6 | 76.0 |
| Base Line M-4 (CDT) | 188.6 | 79.5 | 73.0 |
| Base Line D-11 (PA3A) | 35.5 | 81.2 | 70.6 |
| Base Line D-3 (PA3A) | 58.2 | 77.7 | 77.0 |
| E-2 | 21.2 | 84.4 | 75.9 |
| E-1 | 58.6 | 86.2 | 78.0 |
| G-1 | 43.4 | 92.4 | 92.7 |
| G-5 | 179.6 | 92.7 | 92.2 |
| N-6 | 9.4 | 75.0 | 73.9 |
| N-2 | 47.5 | 79.0 | 71.6 |
| P-7 | 18.3 | 85.0 | 75.6 |
| P-5 | 82.4 | 84.8 | 74.0 |

The hardnesses at the water-cooled end of the contact tips are representative of as-received harnesses. The longest tip life Series G was about 25 percent harder than the other electrodes. The Series E and G contact tips are RWMA-RWAA Group A, Class 2 and Class 3 heat-treatable alloys, respectively. Typical hardnesses and annealing temperatures for these alloys are as follows (a):

| Series | RWMA-RWAA Class | Hardness, RB | Annealing Temp., °F |
|---|---|---|---|
| E | 2 | 80 | 920 |
| G | 3 | 100 | 900 |

The contact tip temperatures during welding that were measured ranged from 570-790F, considerably less than the beginning of hardness

(a) Resistance Welding Manual, Third Edition, Volume II, Resistance Welder Manufacturing Association.

loss of these materials. After cooling from the welding temperature, Series E and P showed significantly higher hardnesses than in the as-received condition. This may be the result of a precipitation hardening effect.

The tungsten-insert tips performed poorly, principally because of an internal obstruction. These tips were swaged which created an I.D. offset at the start of the insert. This offset restricted wire feed. The inserts should have been brazed and then the copper I.D. drilled to eliminate any offset. Additional contact tips with molybdenum-tube inserts are being obtained and will be evaluated although this contract is completed. The results of these evaluations will be made available to Electric Boat.

The Series J contact tips containing Mo wires performed better than the base series. However, the failure mode appeared to be loss of copper between the wires causing the wires to become loose. It is believed that reducing the number of wires to increase their spacing may improve the tip life.

## CONCLUSIONS

The conclusions from this study are as follows:

1. The Series G, RWMA, Class 3 contact tips had an average tip life exceeding the target life, i.e., 99.8 versus 70.0 minutes.

2. As-received hardness of the contact tips should exceed Rockwell B 90 to limit erosion.
3. A wire straightener such as a rotating bent-tube straightener should increase tip life.
4. An adaptive welding power supply that compensates for varying CTOD such as the CRC-Evans CDT will increase tip life.

Results

| | Total Arc Time, min. | Remarks |
|---|---|---|
| 5 | 35.2[a] | Run with CDT, Arc to sidewall |
| 7 | 84.7 | Run with CDT |
| 5 | 53.9 | Run with CDT |
| ) | 188.6 | Run with CDT |
| 5 | 168.8 | Run with CDT |
| - | 14.8[a] | Arc to sidewall |
| - | 9.0[a] | Arc to sidewall |
| 5 | 52.1 | |
| 5 | 106.1 | |
| 4 | 54.7 | |
| ) | 67.3 | |
| | | |
| - | 35.2 | |
| 3 | 40.0 | |
| 1 | 58.2 | |
| ) | 52.4 | |
| 5 | 18.8[b] | Arc to sidewall |
| 2 | 35.5 | |
| AVERAGE | 124.0-CDT | 55.7-PA3A |
| | | |
| ) | 58.6 | |
| 3 | 21.2 | |
| 4 | 6.1[a] | Restriction |
| 3 | 29.1 | |
| 1 | 41.3 | |
| 3 | 52.8 | |
| AVERAGE | 40.6 | |
| | | |
| 3 | 43.4 | |
| ) | 85.3 | |
| 5 | 63.0 | |
| 3 | 127.9 | |
| ) | 179.6 | |
| 3 | 32.0[a] | Arc restart |
| AVERAGE | 99.8 | |

Table 1. Summary of Contact Tip Results - Continued

| Series | Tip No. | Type | Initial I.D. Dia. in. | Final I.D. Minor Axis in. | Final I.D. Major Axis in. | Total Arc Time, min. | Remarks |
|---|---|---|---|---|---|---|---|
| I | 1 | Tubular W-Insert-Spade | l 055 | .059 | .060 | 35.2 | Wire seized |
| | 2 | | .055 | .058 | .058 | 25.1 | Wire seized |
| | 4 | | .056 | .064 | l 066 | 2.5 | Wire seized |
| | | | | | NO AVERAGE | | |
| J | 1 | Mo Wire Insert-Blunt | l 057 | .055 | .058 | 60.8 | |
| | 2 | | .055 | .059 | .080 | 169.6 | |
| | 3 | | .055 | .062 | .065 | 36.5 | |
| | 4 | | .056 | l 059 | .064 | 31.2 | |
| | 5 | | .056 | .061 | .064 | 73.0 | |
| | 6 | | .056 | .063 | .110 | 63.4 | |
| | | | | | AVERAGE | 72.4 | |
| K | 1 | Tubular W-Insert-Blunt | .055 | | | 11.5″ | Apparent arcing between W-insert and Cu |
| | 2 | | l 055 | .056 | .057 | 1.1 | " " " |
| | 3 | | .055 | " | " | | |
| | | | | | NO AVERAGE | | |
| N | 1 | One % W-Cu-Spade | .055 | .068 | .071 | 13*1 | |
| | 2 | | .055 | .060 | .061 | 47.5 | |
| | 3 | | .055 | .058 | .060 | 41.8 | |
| | 4 | | .055 | .068 | .070 | 28.2 | |
| | 5 | | .055 | .053 | .056 | 38.1 | |
| | 6 | | .055 | .058 | .061 | 9.4 | |
| | | | | | AVERAGE | 29.7 | |
| P | 3 | Six % W-Cu-Spade | .055 | l 057 | .079 | 73.1 | |
| | 4 | | .055 | l 059 | .056 | 54.8 | |
| | 5 | | .055 | | | 82.4 | |
| | 6 | | .055 | .055 | .059 | 43.4 | |
| | 7 | | .055 | | | 18.3 | |
| | 8 | | .055 | .056 | .061 | 52.6 | |
| | | | | | AVERAGE | 54.1 | |

(a) Not included in average

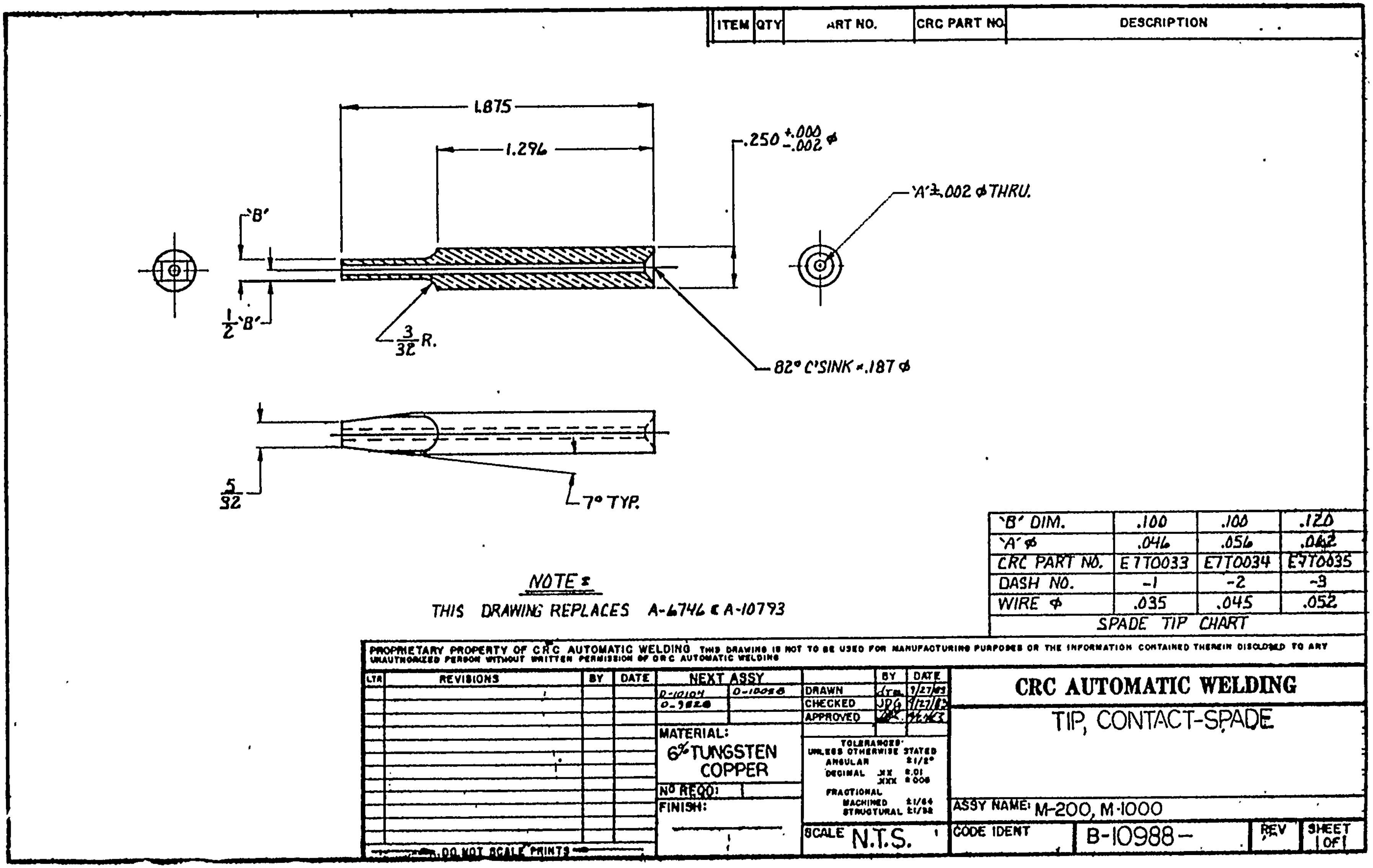
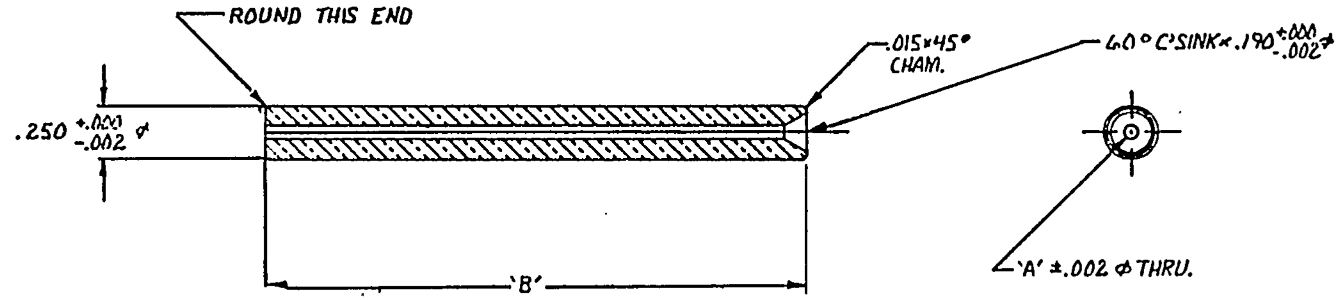



Figure 1. Spade Contact Tip

| ITEM | QTY | PART NO. | CRC PART NO. | DESCRIPTION |
|---|---|---|---|---|




NOTE:
THIS DRAWING REPLACES B-10489

TIP CHART

| | | Ⓐ | Ⓐ | | | | |
|---|---|---|---|---|---|---|---|
| | WIRE ⌀ | .030 | .040 | .035 | .045 | .052 | .062 |
| | 'A' ⌀ | .041 | .051 | .046 | .056 | .064 | .073 |
| 'B' DIM | 2.000 | -17 E7T5011 | -18 E7T5012 | -1 E7T0036 | -2 E7T0037 | -3 E7T0038 | -4 E7T0039 |
| | 2.500 | -19 E7T5033 | -20 E7T5034 | -5 E7T0040 | -6 E7T0021 | -7 E7T0028 | -8 E7T0030 |
| | 3.000 | -21 E7T5035 | -22 E7T5036 | -9 E7T0041 | -10 E7T0042 | -11 E7T0043 | -12 E7T0044 |
| | 3.500 | -23 E7T5037 | -24 E7T5038 | -13 E7T0045 | -14 E7T0046 | -15 E7T0029 | -16 E7T0031 |

DASH NO.
CRC PART NO.



| LTR | REVISIONS | BY | DATE |
|---|---|---|---|
| A | ADDED PARTS | C.J. | 8-27-66 |

NEXT ASSY: D-10104, D-10058, D-9828, C-50427-

| | BY | DATE |
|---|---|---|
| DRAWN | | 9/21/83 |
| CHECKED | JDG | 9/27/83 |
| APPROVED | | |

MATERIAL: 6% TUNGSTEN COPPER

NO REQD: 1

FINISH:

TOLERANCES: UNLESS OTHERWISE STATED ANGULAR ±1/2° DECIMAL .XX ±.01 .XXX ±.005 FRACTIONAL MACHINED ±1/64 STRUCTURAL ±1/32

CRC AUTOMATIC WELDING

TIP, CONTACT

ASSY NAME: M-200, M-1000, M-1400

SCALE N.T.S. | CODE IDENT | B-10989- | REV | SHEET 1 OF 1

DO NOT SCALE PRINTS

Figure 2. Blunt Contact Tip

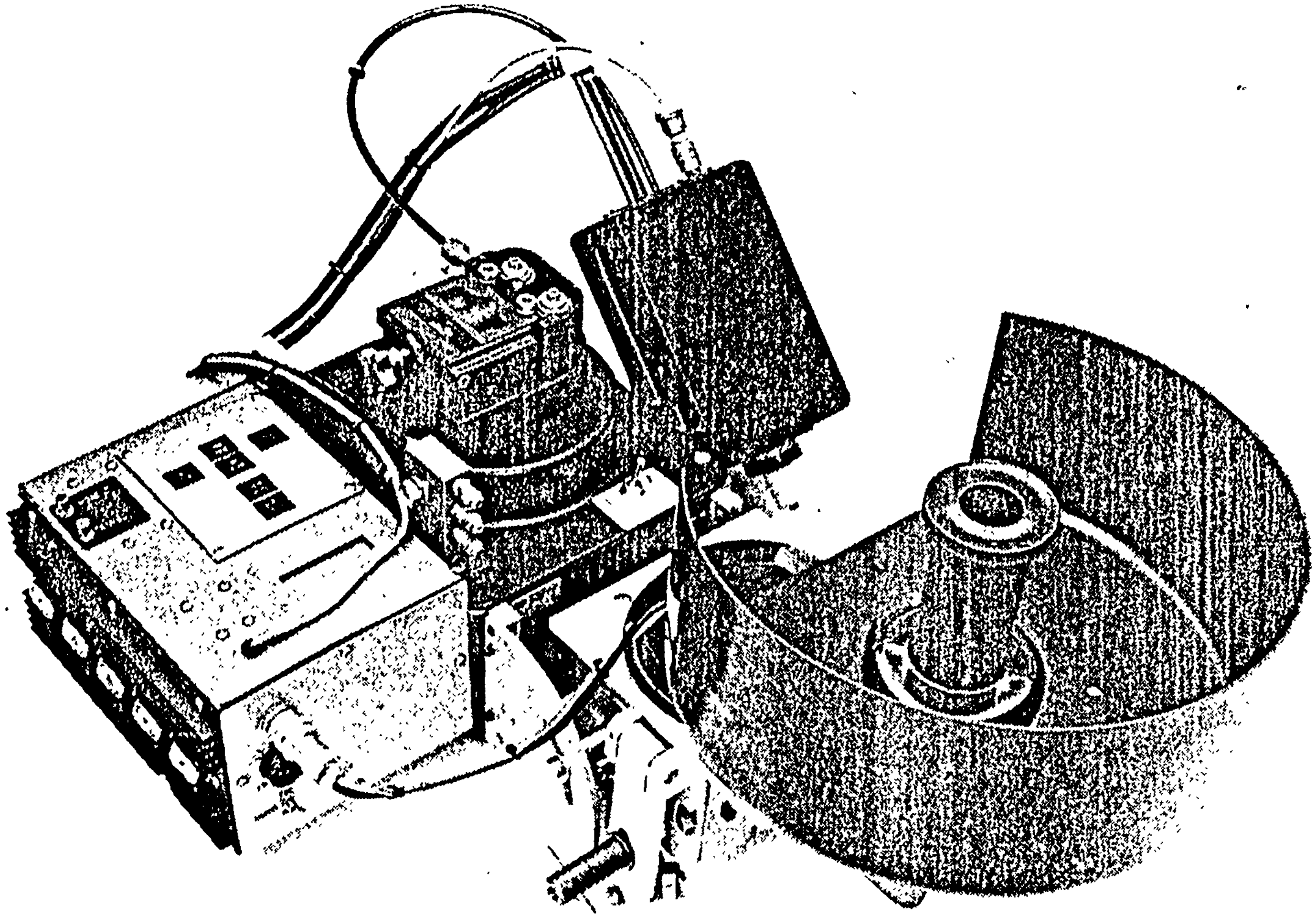
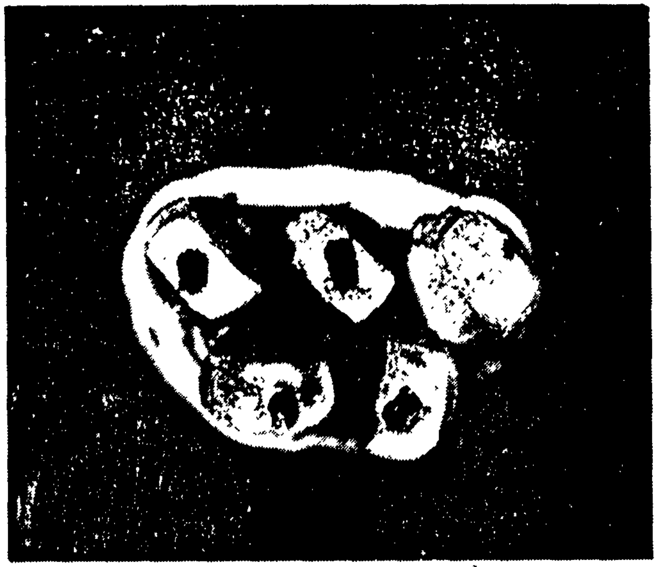


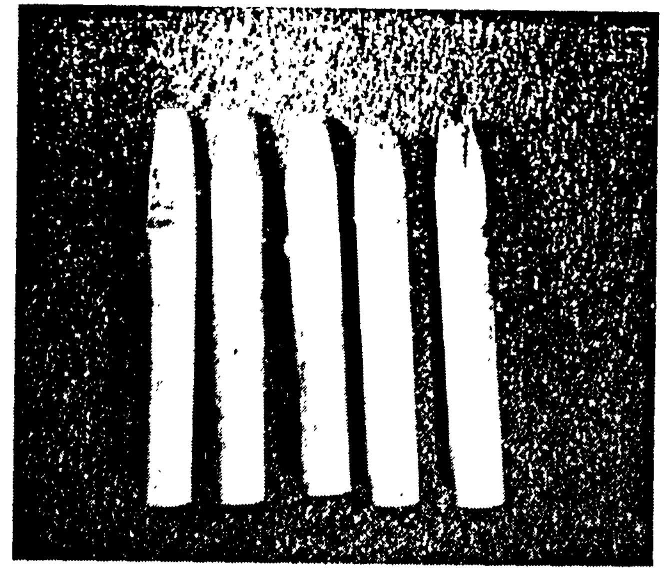
Figure 3. M-1000 Welding Carriage

M-1 M-2 M-3



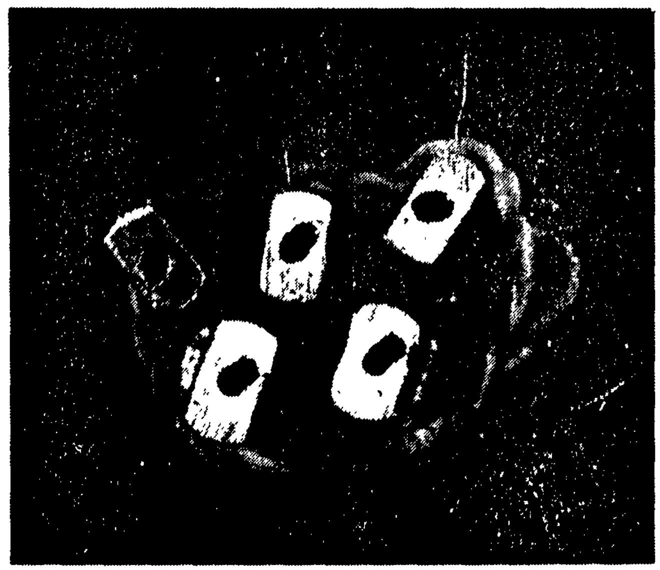
M-4 M-5

4A As Welded



4B As Welded

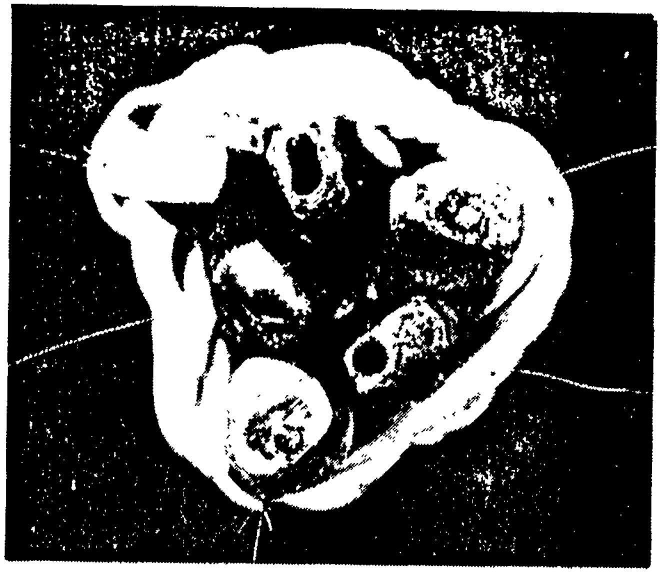
M-1 M-2 M-3



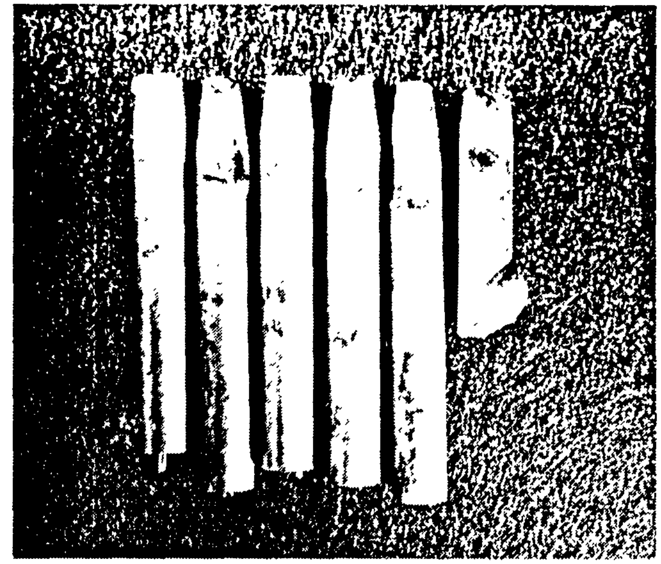
M-4 M-5

4C Trimmed

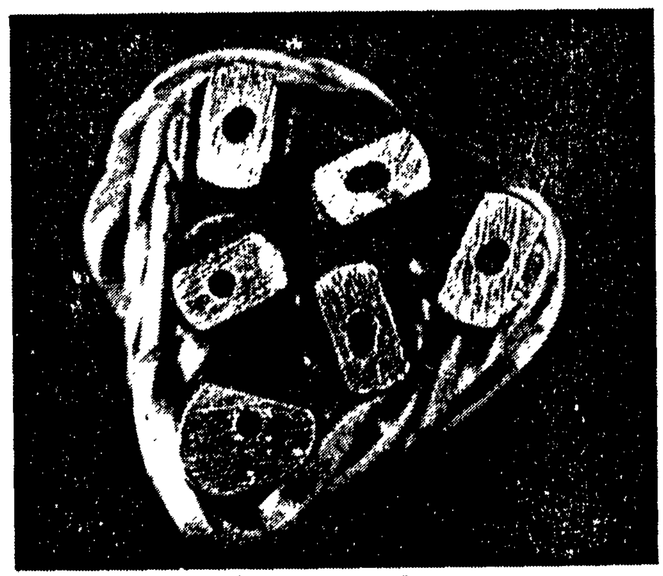
Figure 4. Base Line Series M Deposited With CTD




5A As Welded




5B As Welded




5C Trimmed

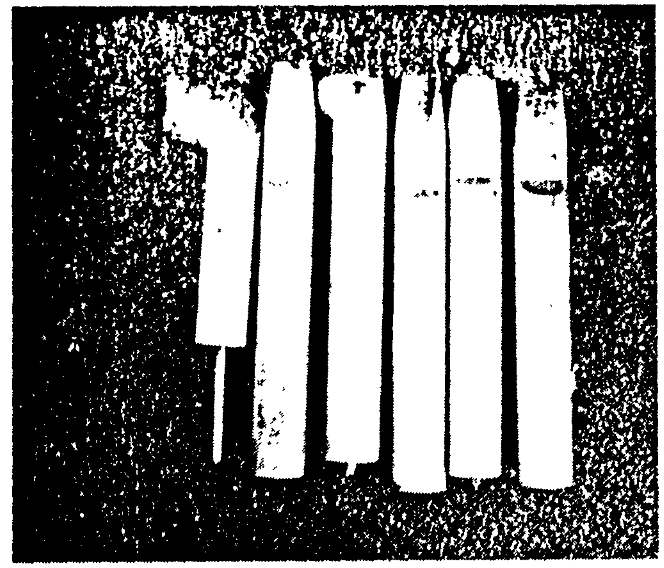
Figure 5. Base Line Series M Deposited With PA3A

D-1 D-2 D-3

D-4 D-11 D-10

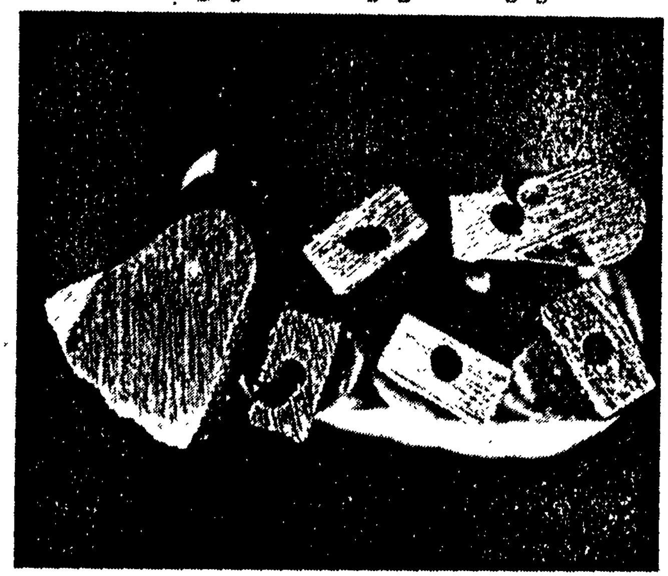
6A As Welded

D-1 D-2 D-3 D-4 D-10 D-11



6B As Welded

D-1 D-2 D-3

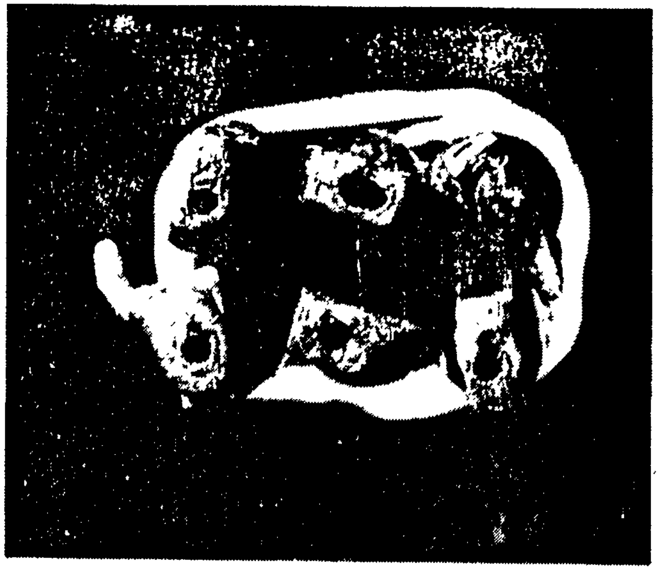


D-4 D-10 D-11

6C Trimmed

Figure 6. Base Line Series M (Marked D)

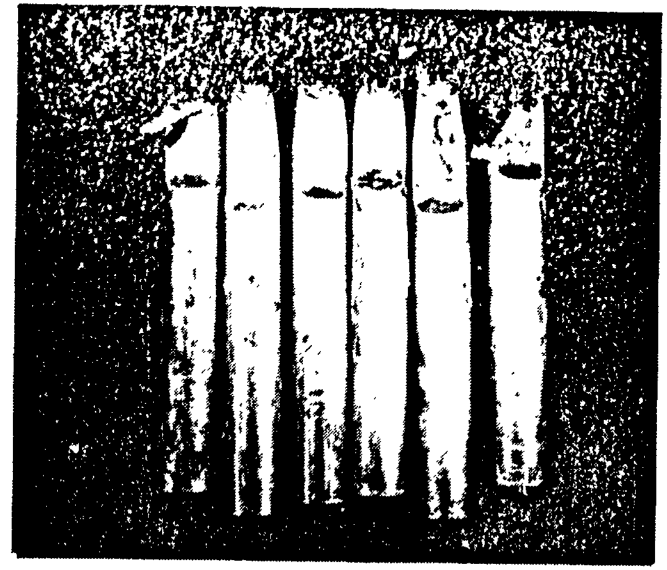
E-4 E-5 E-6



E-1 E-2 E-3

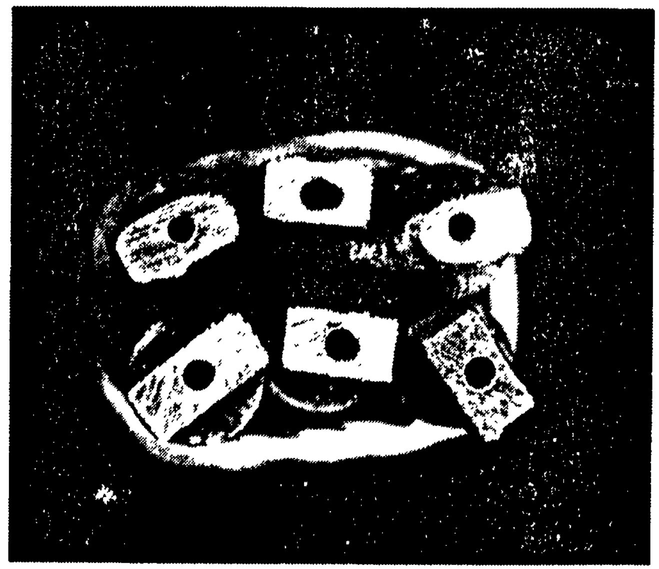
7A As Welded

E-1 E-2 E-3 E-4 E-5 E-6



7B As Welded

E-4 E-5 E-6

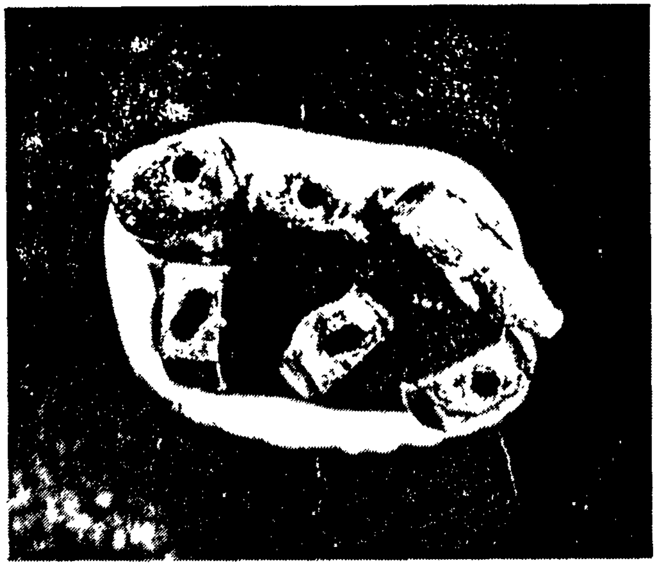


E-1 E-2 E-3

7C Trimmed

Figure 7. Series E

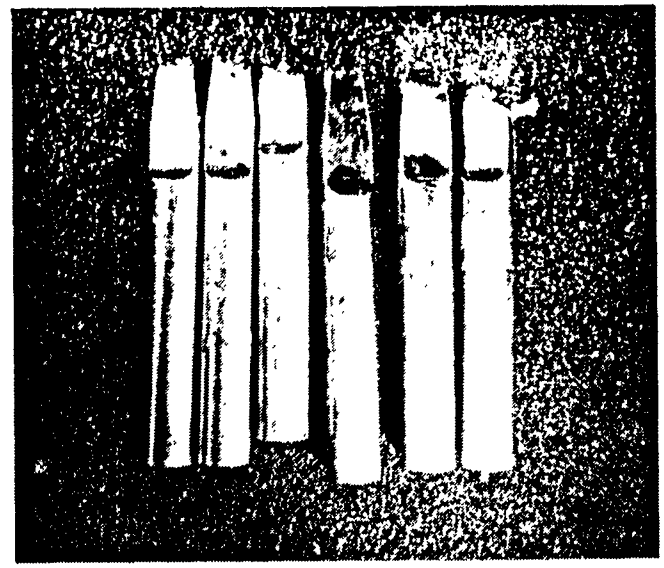
G-5 G-3 G-6



G-4 G-2 G-1

8A As Welded

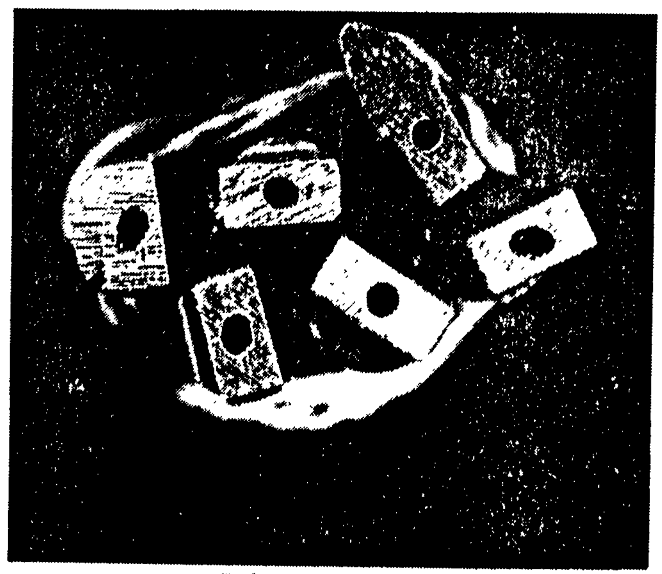
G-1G-2 G-3 G-4 G-5 G-6



8B As Welded

G-2 G-6

G-5



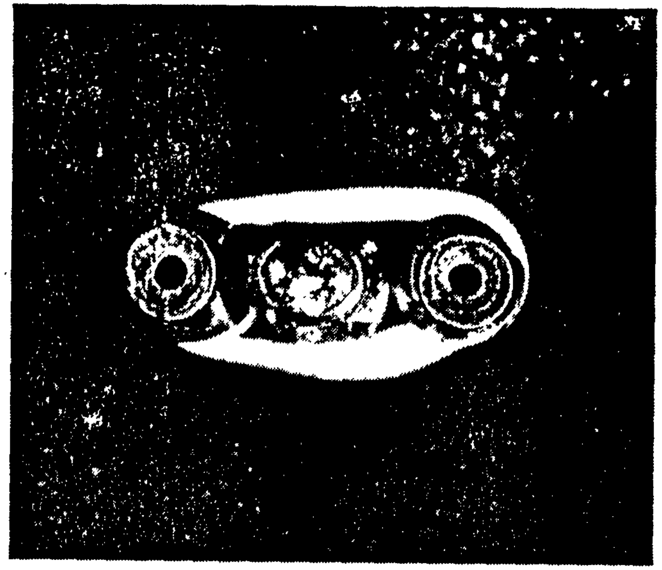
G-4

G-1 G-3

8C Trimmed

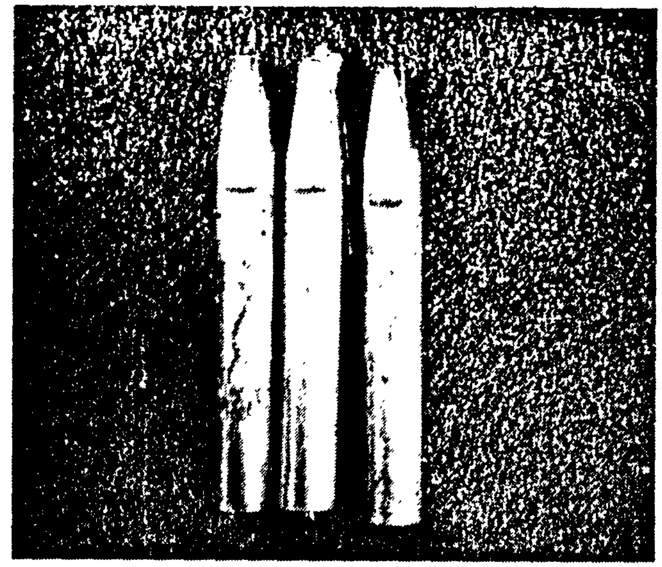
Figure 8. Series G

I-1 I-2 I-4



9A As Welded

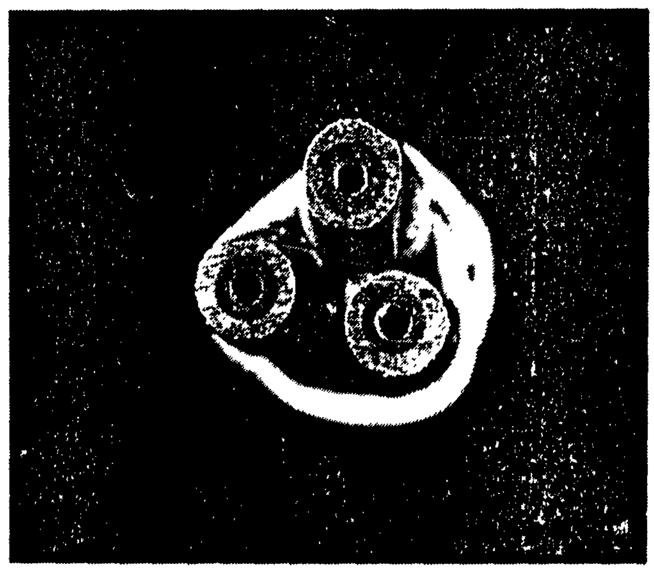
I-1 I-2 I-4



9B As Welded

I-2

I-1

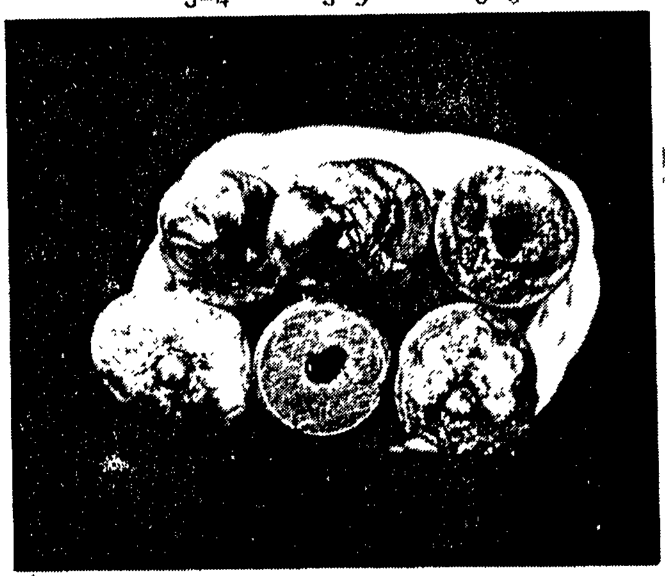


I-4

9C Trimmed

Figure 9. Series I

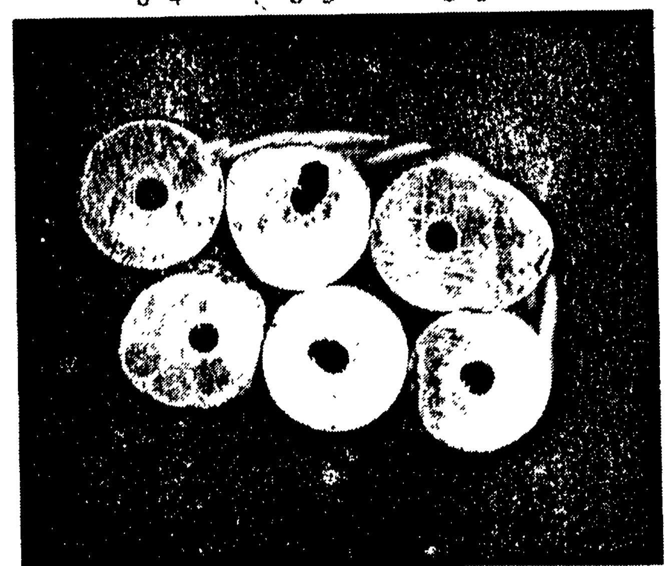
J-4 J-3 J-6



J-1 J-2 J-5

10A As Welded

J-4 J-3 J-1



J-5 J-2 J-6

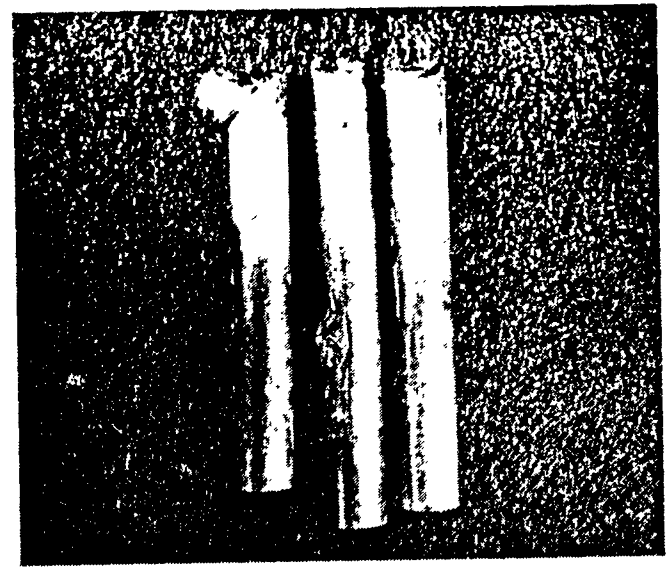
10B Trimmed

Figure 10. Series J

K-1 K-2 K-3

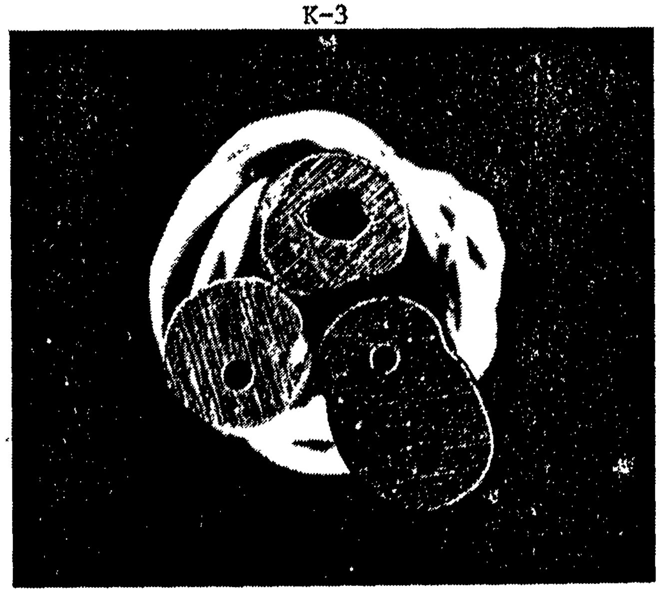
11A As Welded

K-1 K-2 K-3



11B As Welded

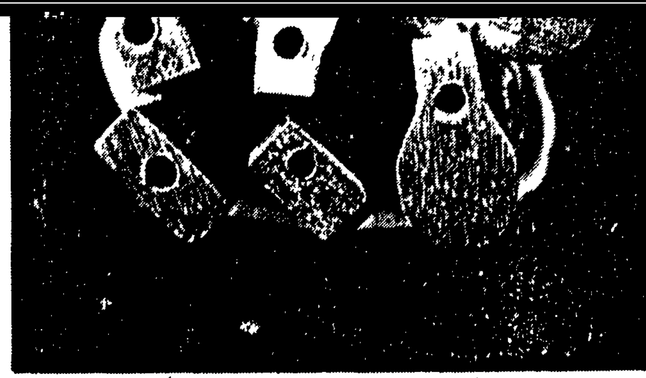
K-3



K-2 K-1

11C As Trimmed

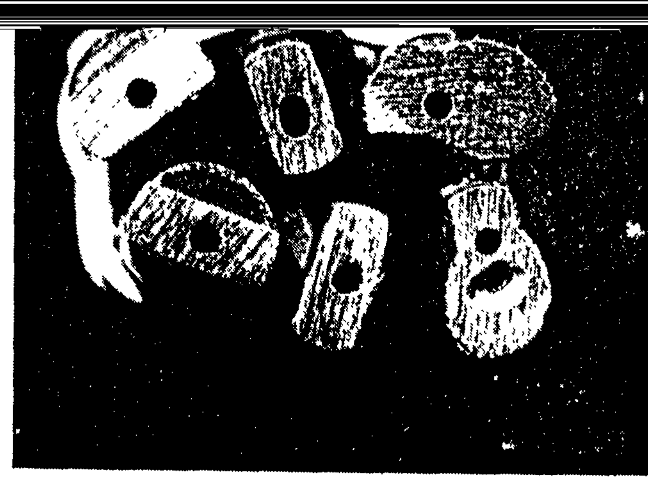
Figure 11. Series K



N-4 N-5 N-6

12C Trimmed

Figure 12. Series N



P-7 P-8 P-5

13C Trimmed

Figure 13. Series P